



Modelling and analysis of an improved PV array Model Incorporating Shading Parameters based on Variations in Temperature and Irradiance.

¹Saidu, S., ²Okorie, P. U., ³Olarinoye, G. A., ⁴Momoh, I. O., ⁵Umar, A.

^{1,2,3,4} Electrical Engineering Department,

Ahmadu Bello University Zaria.

⁵Computer Engineering Department,

Ahmadu Bello University, Zaria.

ABSTRACT

The performance of solar photo-voltaic array is greatly influenced by the conditions of the solar cells, such as the insolation and temperature received by the solar cells. This proposed work is based on modelling and analysis of an improved PV array model under partial shading condition. This is based on introducing shading parameter as a function of temperature and irradiance in to the general model. A Matlab-based Simulink model is developed on the basis of Shockley diode equations. The developed model is employed to predict accurately the characteristic curves of a PV array considering different degree of shadings. In order to validate the accuracy and effectiveness of the proposed model, different simulations were carried out involving uniform and partially shaded conditions across PV array with bypass diodes. The proposed model was compared with the parameters of the conventional Model of the PV array using maximum power point, open-circuit voltage, and short-circuit current, as the performance metrics.

ARTICLE INFO

Article History

Received: April, 2019

Received in revised form: May, 2019

Accepted: June, 2019

Published online: November, 2019

KEYWORDS

Photo Voltaic, Partial shading condition, Maximum Power Point

INTRODUCTION

Due to high rate of energy demand and environmental concern such as global warming, renewable energy sources such as Solar energy, Wind, Biomass, Hydro, Geothermal among others are catching the interest of the researchers (Mao *et al.*, 2017). Among all the renewable energy sources, solar energy is one of the cleanest, most reliable and easy to harness energy (Dolara *et al.*, 2018). Despite high cost of the solar module, solar system is used due to its minimal cost of maintenance, zero emissions of CO₂, no moving parts to break down and long life cycle (Mao *et al.*, 2017). Different modelling techniques, algorithms and control techniques have been reviewed in the course of this work. Many researchers proposed modified PV array model on different approaches in the area in order to improve the performance of the PV array model efficiently under standard and partially shaded conditions. Some of the existing models were build based on standard test condition using single or double diode technique. Among the proposed techniques only few methods were adopted in practical PV application. Literatures have shown that photovoltaic systems are affected by factors that reduce their efficiency such as: Partial shading on the photovoltaic panel, changes on cells temperature,

changes on irradiation, and impedance variations at the system output among others. All these factors change the behaviour of the panel or PV array, which is normally defined by the output I-V and P-V curves and consequently, the Maximum Power Point (MPP) of the panel/array, is also modified. Therefore, a photovoltaic system needs to be optimized in terms of power production. The proposed model implement an improved model of a PV array in form of Matlab/Simulink using single diode Shockley equations to minimize switching losses due to bypass diode and improve the performance of the PV array model.

The following steps were considered in the Modeling and analysis of an improved PV array model under partially shaded conditions:

1. Modelling of the PV Cell
2. Modeling Techniques
3. Single Diode (SD) Model
4. Mathematical method base on the objective function base on single diode equations of PV cell.
5. Partial shading condition on PV array
6. Shading effect on PV system with bypass diodes
7. Modeling of the photovoltaic system under partially shaded conditions

Modelling of the PV Cell

PV cells can be modelled as a current source in parallel with a diode (John *et al.*, 2017). It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current (Wei *et al.*, 2017). The PV cell behaves like a diode when there is no light present to generate any current. The intensity of incident light is directly proportional to the current generated by the PV cell (Raina *et al.*, 2013).

Modeling Techniques

The two basic modeling techniques use to represent a PV model are single diode and double diodes modeling techniques other techniques are used for theoretical understanding of PV cell (Mohapatra *et al.*, 2017). Most of the literature employed single diode model due to less number of parameters to be determined and simplicity of the model compared to the double diode technique. This research work employed single diode modeling technique because of its reduced computational burden due to less number of Parameters and simplicity of the model.

Single Diode (SD) Model

The main aim of mathematical modeling of PV array is to depict the behavior and to study the characteristic of the PV modules (Raina *et al.*, 2013). Due to less number of parameters to be determined and simplicity of the model, a single diode model is used in this work and is shown in Fig.1 (Yang *et al.*, 2017).

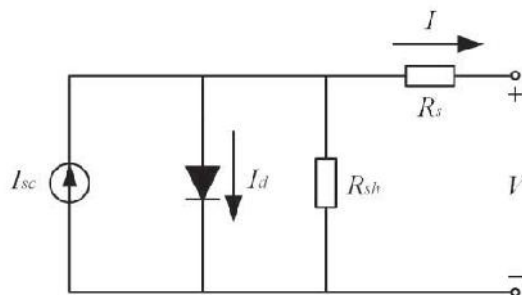


Figure 1: Single Diode model of a PV Cell (Yang *et al.*, 2017)

By applying Kirchoff's law to the circuit above (Fig 1), the output current of the PV Cell can be obtained as (Yang *et al.*, 2017):

$$I = I_{sc} - I_d - I_{sh} \quad (1)$$

$$I_{sh} = \frac{V + IR_s}{R_{sh}} \quad (2)$$

$$I_d = I_0 \left(e^{\frac{V + IR_s}{AVT}} - 1 \right) \quad (3)$$

$$I = I_{sc} - I_0 \left(e^{\frac{q(V + IR_s)}{AKT}} - 1 \right) - \frac{V + IR_s}{R_{sh}} \quad (4)$$

Where;

I_{sc} : Photocurrent generated by the incidence of light(A), I_d Diode Current (A), I_0 Diode Reverse Saturation Current (A), R_s Series Resistance (Ω), R_{sh} Shunt Resistance (Ω), V is the output voltage of the PV cell, A Diode Ideality Factor, T Absolute Temperature in Kelvin, q Electron Charge ($1.60217646 \times 10^{-19}$ C) K Boltzmann Constant ($1.3806503 \times 10^{-23}$ J/K).

Equation (4) is applicable to theoretical analysis of PV cell and is obtained based on physical principle of PV cell. But in practical application, the Parameters in the PV cell model are difficult to determine, this make single diode model of PV cell inconvenient for project application (Yang *et al.*, 2017). The engineering analytical model of PV cell can be obtained by approximate substitution of the three assumptions below from equation (4) (Yang *et al.*, 2017):

1. $\frac{V + IR_s}{R_{sh}}$ has been neglected
2. Under open-circuit condition, $I = 0$, $V = V_{oc}$
3. At the maximum power point, $V = V_m$, $I = I_m$.

The engineering analytical model of PV cell take in to accounts short circuit current I_{sc} , open circuit voltage V_{oc} , maximum power current I_m and maximum power voltage V_m . Equation (5) described engineering analytical model (Yang *et al.*, 2017):

$$I = I_{sc} \left(1 - C_1 \left\{ \exp \left[\frac{V}{C_2 V_{oc}} \right] - 1 \right\} \right) \quad (5)$$

Where:

$$C_1 = \left(1 - \frac{I_m}{I_{sc}} \right) \exp \left[\frac{-V}{C_2 V_{oc}} \right] \quad (6)$$

$$C_2 = \left(\frac{V_m}{V_{oc}} - 1 \right) \left[\ln \left(1 - \frac{I_m}{I_{sc}} \right) \right]^{-1} \quad (7)$$

The higher the temperature, the more the concentration of the intrinsic charge carriers increased and consequently results in higher carrier recombination. Therefore, rise in temperature increases the reverse saturation current (I_0) which is primarily dependent on the temperature of the cell, to calculate the diode saturation current (I_0) according to variations in cell temperature, (2.8) is used (Bikaneria *et al.*, 2013).

$$I_0 = \frac{(R_{sh} + R_s) I_{sc} - V_{oc}}{R_{sh} e^{\frac{V_{oc}}{AVT}}} \quad (8)$$

The two important parameters of the I-V and P-V characteristics are the open Circuit voltage

V_{oc} and the short circuit current I_{sc} . At both points the power generated is zero. V_{oc} can be approximated from (4) when the output current of the cell is zero, i.e. $I=0$ and the shunt resistance R_{sh} is neglected. It is represented by (10). The short circuit current I_{sc} is the current at $V = 0$ and is approximately equal to the light generated current (I_L) (Ovaska, 2010).

$$V_T = \frac{n_s k T}{q} \quad (9)$$

$$V_{oc} = V_T \ln \left[\frac{I_L}{I_0} + 1 \right] \quad (10)$$

Where: n_s :number of Series connected Cells, T , P-N Junction's temperature (K). The photocurrent can be calculated using (11). This equation is a function of temperature and irradiance values, the dependence of the photocurrent on the irradiance and cell temperature can be described by (11) (Townsend,

$$I_{sc} = \frac{I_{sc,ref}}{G_{T,ref}} G_{TC} - A(T_c - T_{c,ref}) \quad (11)$$

1989). where, G_{TC} , Irradiance (W/m^2), $G_{T,ref}$, Reference irradiance ($1000 W/m^2$), $I_{sc,ref}$ Reference condition's short circuit current (A), A , Curve Fitting Parameter, T_c , Condition Temperature, $T_{c,ref}$, Reference Temperature ($25^\circ C$), A is the junction perfection factor or ideality factor, which determines the diode deviation from the ideal p-n junction (Shams El-Dein, 2012). The PV array power can be calculated using equation (12).

$$P = IV = n_p I_x V - n_p V I_d \left[\exp \left(\frac{q}{k T A} \frac{V_{oc}}{n_s} \right) - 1 \right] \quad (12)$$

Shading effect on PV system with bypass diodes.

Consider a PV array with n individual PV module connected in series-parallel configuration, having n_s modules with n_p parallel path will satisfied the following equations:

$$n = n_s \times n_p \quad (13)$$

Each module has bypass diode connected in parallel with it; the shading will cause the output of each module to be degraded by a factor which depends on the degree of shading. The characteristic of the system can be defined as:

$$I_{SCsys} = I_{SCm} \times n_p \quad (14)$$

$$V_{OCsys} = V_{OCm} \times n_s \quad (15)$$

Bypass diode is set to conduct under partial shading condition when equation (16) is satisfied (Mohapatra *et al.*, 2017). It occurs at a point called the Inflection Point, it is a point where the string current is higher than the short circuit current of a particular cell and it defines the current and voltage

conditions in which the bypass diode becomes active.

$$V_2 - \sum_{i=1}^n V_i \geq V_{DD}, \quad i \neq 2 \quad (16)$$

Where V_{DD} is the forward bias voltage of the diode.

Partial Shading Condition on PV Array

Partial Shading Condition (PSC) is the condition at which PV array received non uniform insolation (Dolara *et al.*, 2018). Insolation and Temperature greatly influence the GMPP of a PV array. Due to change in weather condition, irradiance and temperature varies, hence the GMPP also change, this necessitate the need to track the GMPP again in order to avoid influence due to global peak changing to local peak (Duan *et al.*, 2015). Under PSC, the actual power of the PV array is less than the theoretical value. Partial shading can be detected using equation. This also satisfied the restarting conditions.

$$P_{PV} \left[\frac{G}{G_{ST}} \right] [1 + \alpha_p (T - T_{STC})] > P_{real} \quad (17)$$

Where, P_{real} is the actual output maximum Power, P_{PV} , is the rated power of the PV module, G is the actual solar insolation, G_{ST} is the insolation under standard test conditions (w/m^2), α_p is the temperature coefficient of power of PV module ($-0.35\%/^\circ C$), T is the actual temperature of the PV Module. T_{STC} is the temperature under standard test condition ($25^\circ C$). In order to minimize power losses due to bypass diodes, equation (16) is introduced to control the turn ON process depending on whether the effect of bypass diodes is required or not, the bypass diodes turn ON only if equation (16) is satisfied. This is beneficial to minimize switching losses and improve the steady state performance of the PV model.

Modeling of the photovoltaic system under partially shaded conditions

The formulas given by the equations (1-12), were used in developing the model of the PV array configuration under partially shaded condition. The entire system has been modeled using MATLAB/Simulink R2015b. A model-based MPPT strategy that is suitable for various environmental conditions were modeled in two different patterns, Pattern 1 is under uniform environmental condition, the temperature and irradiance at standard test condition were used ($25^\circ C$ and $1000 w/m^2$), and pattern 2 under rapidly changing environmental conditions, in this pattern variation in temperature

and irradiance are taken in to consideration. The inputs to the solar PV panel are temperature, solar irradiance, number of solar cells in series, and number of rows of solar cells in parallel. The PV array includes two PV panels connected in series. The parameters of the single PV cell simulation under standard test condition (STC) were adopted from the work of Yang *et al.* (2017) as shown in table 1.0.

Parameters	Values
Cell temperature (deg.c)	25
Air mass	1.5
Insolation (W/m ²)	1000
Open-circuit voltage (V)	21.6
Short-circuit current (A)	2.25
Temperature coefficient of Isc (%/deg. C)	0.038
Temperature coefficient of Voc (%/deg. C)	-0.3738
Number of series connected module per string	1
Parallel string	1
Light-generated current I _L (A)	2.2637
Diode saturation current I ₀ (A)	1.148e-10
Diode ideality factor	0.65947
Shunt resistance (Ohms)	103.7418
Series resistance (Ohms)	0.63239

Table 1.0 parameters of the PV array model

Figure 2 shows the block diagram of the modeled Solar PV array considering partial shading.

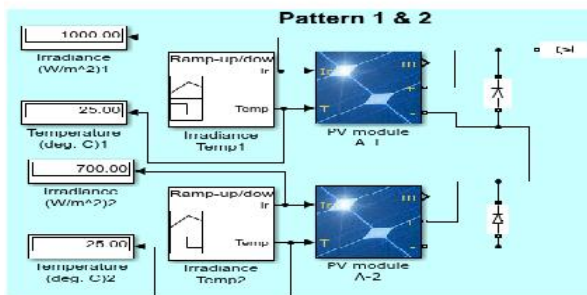


Figure 2 modeled Solar PV array considering partial shading.

RESULTS AND DISCUSSIONS

In this stage, variation in temperature and irradiation representing various degree of shading was analysed.

I-V Curves with varying degree of shading due to variation in solar irradiance

The degree of shading depends on the variation of temperature and irradiance. At STC temperature and varying irradiance, it can be observed that decrease in irradiance causes the short circuit current (I_{sc}) to decrease widely with slightly decrease in open circuit voltage (V_{oc}) and vice versa. The MPP can be seen to vary slightly depending on the variation of solar irradiance as shown in figure 3. Increase in irradiance causes increase in MPP.

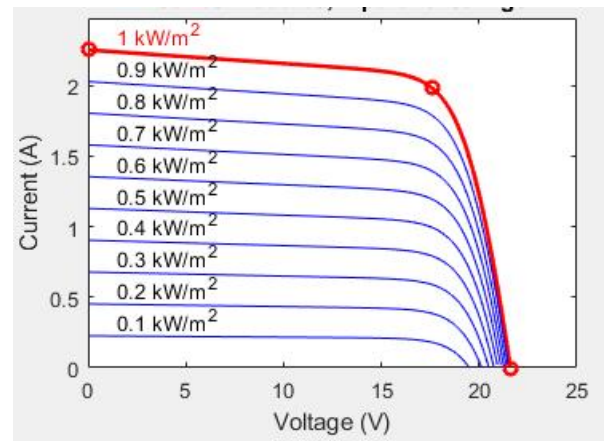


Figure 3 I-V curve of a PV module with variation in solar irradiance.

P-V Curves with varying degree of shading due to variation in solar irradiance

Figure 4 shows the P-V curve of a PV module with variation in solar irradiance, it can be observed that increase in irradiance causes major increase in power with marginal increase in open circuit voltage and vice-versa. Increase in irradiance increases the total generated power.

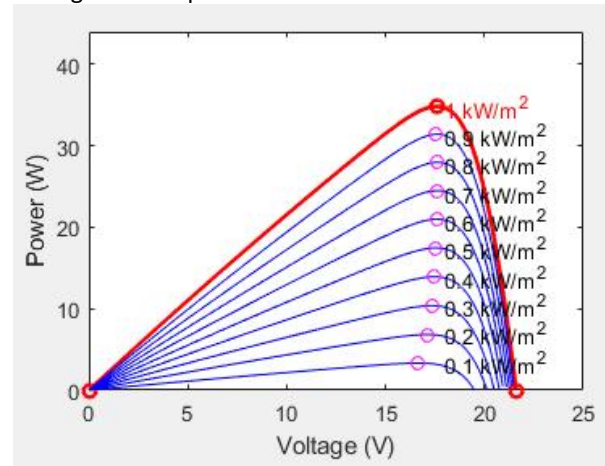


Figure 4 P-V curve of a PV module with variation in solar irradiance at constant temperature.

I-V Curves with varying degree of shading due to variation in temperature

The variation in temperature greatly influence the performance of a PV system, increase in the panel temperature causes major decrease in open circuit voltage with very slight increase in short circuit current in the I-V characteristic curve as shown in figure 5 and consequently reduces the total generated power and vice-versa.

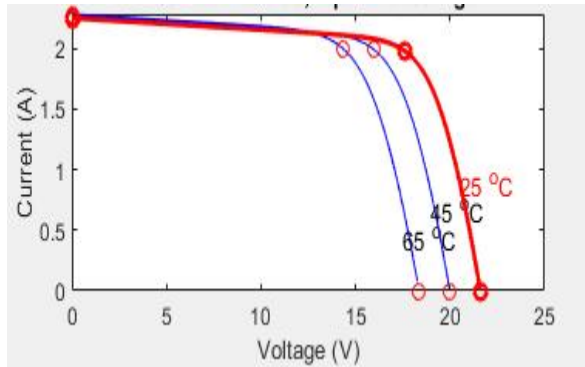


Figure 5 I-V Curves for different Temperature levels at constant irradiance

The increase in panel temperature causes major reduction in the PV panel output power due to reduction in fill factor caused by reduced open circuit voltage.

2.6.4 I-V Curves with varying degree of shading due to variation in temperature

Figure 6 shows the effect of temperature variation on P-V characteristic curve of a PV array. It can be observed that the MPP increases with decrease in temperature and decreases with increase in temperature. Therefore, it is very important to operate a PV system within the normal operating temperature. Increase in cells temperature can causes serious overheat which may lead to the occurrence of hotspot which reduces the total generated power and may end up damaging the entire PV system.

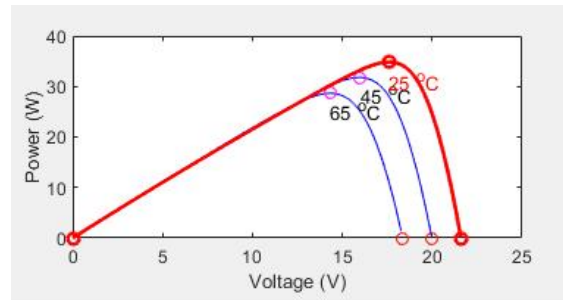


Figure 6 P-V Curves for different Temperature levels at constant irradiance.

I-V and P-V characteristics curves under standard and partially shaded conditions.

The PV array includes two PV panels connected in series as shown in figure 2. The parameters of the simulation of the PV array are shown in table 1. In order to check the effectiveness and superiority of the proposed method under partially shaded condition, we designed simulation and experiment between the proposed method and the normal conventional PV model. In order to simulate different shading situation for P V array, we creates a sudden changes in the insolation of the second PV Panel from 1000W/m² to 7000W/m² at 0.3s in the simulation process. It is observed that the maximum power decreased significantly from 70W to 52.3W due to unequal insolation condition. At this point the restarting conditions are satisfied and therefore, the proposed method restarts for MPPT control. Figure 7 shows the different PV curve under varying insolation condition, under standard test and partially shaded conditions. It can be observed that the I-V curve produces multiple steps whereas the P-V curve produces multiple peaks under partially shaded condition, the PV characteristic curve produces one peak under STC.

The PV array includes two PV panels connected in series as shown in figure 2. The parameters of the simulation of the PV array are shown in table 1.0.

In order to simulate different shading situation for PV array, we created a sudden changes in the insolation of the second PV Panel from 1000W/m² to 7000W/m² at 0.3s in the simulation process.

It is observed that the maximum power decreased significantly from 70W to 52.3W due to unequal insolation condition.

Figure 7 shows the different PV characteristic curves under standard test and

partially shaded conditions. It can be observed that at STC, the I-V and P-V characteristic curves produce a unique operating point, whereas the I-V curve produces multiple steps and the P-V curve produces multiple peaks under partially shaded condition.

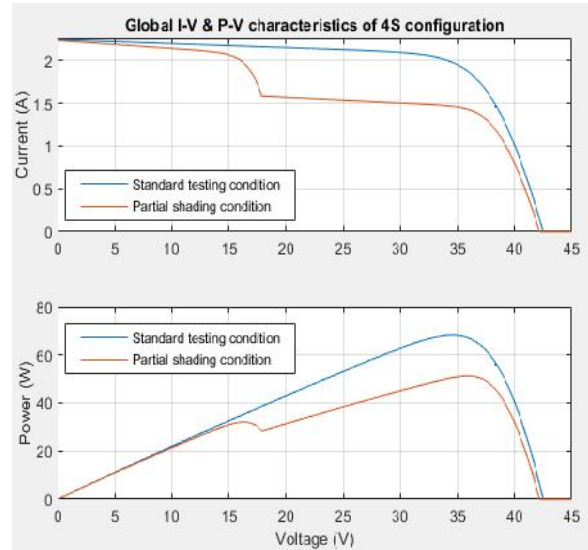


Figure 7 I-V and P-V characteristics curves under standard and partially shaded condition

CONCLUSION

This paper presents a PV array model in Matlab/Simulink environment using the generalized mathematical model equations of a single diode model of a solar PV array. Proposed work has shown improvement over the conventional models on the P-V and I-V characteristic curves. The proposed model was compared with the parameters of the conventional Model of the PV array presented in the work of Yang et al. (2017) using maximum power point, open-circuit voltage, and short-circuit current, as the performance metrics. As shown in figure 7, the proposed model showed accuracy improvement by 2.91%, 0.37%, and 1.74% for maximum power point, open-circuit voltage, and short-circuit current respectively at STC. Under PSC, the proposed model showed accuracy improvement by 1.69%, 0.73%, and 0.73% for maximum power point, open-circuit voltage, and short-circuit current respectively.

REFERENCES

Bikaneria, J., Joshi, S. P., & Joshi, A. (2013). Modeling and Simulation of PV Cell using One-diode model. *International journal of scientific and research publications*, 3(10), 1-4.

- Dolara, A., Grimaccia, F., Mussetta, M., Ogliari, E., & Leva, S. (2018). An Evolutionary-Based MPPT Algorithm for Photovoltaic Systems under Dynamic Partial Shading. *Applied Sciences*, 8(4), 558.
- Duan, Q., Leng, J., Duan, P., Hu, B., & Mao, M. (2015). An improved variable step PO and global scanning MPPT method for PV systems under partial shading condition. Paper presented at the 2015 7th International Conference on Intelligent Human-Machine Systems and Cybernetics.
- John, R., Mohammed, S. S., & Zachariah, R. (2017). Variable step size Perturb and observe MPPT algorithm for standalone solar photovoltaic system. Paper presented at the 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS).
- Mao, M., Duan, Q., Duan, P., & Hu, B. (2017). Comprehensive improvement of artificial fish swarm algorithm for global MPPT in PV system under partial shading conditions. *Transactions of the Institute of Measurement and Control*, 0142331217697374.
- Mohapatra, A., Nayak, B., Das, P., & Mohanty, K. B. (2017). A review on MPPT techniques of PV system under partial shading condition. *Renewable and Sustainable Energy Reviews*, 80, 854-867.
- Ovaska, S. (2010). Maximum power point tracking algorithms for photovoltaic applications. *Diss. Aalto University*.
- Raina, G., Patil, M. D., Mandal, S., Hedau, R., & Shinde, S. (2013). A novel technique for PV panel performance prediction. *International Journal of Computer Applications*, 975, 8887.
- Shams El-Dein, M. (2012). Novel Designs for Photovoltaic Arrays to Reduce Partial Shading Losses and to Ease Series Arc Fault Detection.
- Townsend, T. U. (1989). *A method for estimating the long-term performance of direct-coupled photovoltaic systems*. University of Wisconsin--Madison.
- Wei, T., Liu, D., & Zhang, C. (2017). An Improved Particle Swarm Optimization (PSO)-Based MPPT Strategy for PV System. Paper presented at the MATEC Web of Conferences.



Yang, Z., Duan, Q., Zhong, J., Mao, M., & Xun, Z. (2017). *Analysis of improved PSO and perturb & observe global MPPT algorithm for PV array under partial shading condition*. Paper presented at the Control And Decision Conference (CCDC), 2017 29th Chinese.