Control for Seamless Formation and Robust Operation in DG Microgrids

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ABSTRACT- ***One of the major problem faced by the Indian power grid system are the excess use of energy. The utilization of renewable energy is the only solution to overcome this deficiency. Here we propose a system with photovoltaic system as renewable energy source act as a microgrid serving the grid. But while integrating, the power system stability is a crucial criteria. Inorder to facilitate powerful and flexible control infrastructure in future smart power grids, it is very essential to obtain the seamless formation and robust control of distributed generation microgrids. To achieve this objective, this paper presents a control structure for microgrid converters based on two controllers direct voltage controller and transient droop controller for power sharing. The proposed scheme have a salient feature of minimum switching actions between grid connected and isolated microgrids systems so that it minimize the internal microgrid formation disturbances like voltage magnitude disturbances and power angle swings associated with mode transition and load disturbances. This idea was implemented in MATLAB Simulink with photovoltaic as the source with controlling part to mitigate all the disturbances, to obtain the stable system***

Keywords— Microgrids, Power System Stability, Robust Control, Renewable Resource.

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1. INTRODUCTION

Nowadays the magnitude of growth of load demand is higher than the generation. To compensate the future growth demand, the use of renewable energy sources will be effective method to meet the demand and also will be the best solution to meet the consumer requirement during the power breakdown. If the customer have a renewable energy sources at house he can either switch on to grid or the microgrid. But the quality of the power and power system stability is a major issue while integrating the renewable energy to the grid. So inorder obtain a flexible power system we use two controllers to maintain the power system stability. While considering the India's electrical sector, the total installed capacity is of 67789.94MW, 29% for central and in state wide it is 91437.70MW, 38% of electricity as of 2014 February. Renewable power plant constitutes 33791.7MW. The lack of investment in renewable energy keeps India in national energy dependence on foreigners to satisfy the power demands. India faced a power blackout in 2012 that put most of the northern states in dark for 3 days due to a fault in the grid .So if we integrate renewable energy to the smart grid at distribution level or in each house we can meet the power demand and can avoid power shortage. It is still a challenge to integrate efficiently those intermittent resources in the grid at distribution side. But there are so many disturbances problems while integrating the renewable energy to the grid which affects power system stability and the power quality.

In the proposed system, if AC power is not there ie., when black out occurs, then the system will use the solar energy optimally and effectively to satisfy the customer power demand and vise versa. The PV system is installed at each house and PWM-VSI inverter is used for supplying the appliances. To offer flexible infrastructure seamless formation and robust operations in grid connected mode and isolated mode, two controllers are used. To enhance the robustness of the control system adaptive direct voltage controller and a transient droop controllers are used. While transition between grid and isolated modes, various disturbances will be formed includes voltage magnitude disturbances and power angle disturbances. Seamless voltage transfer control between grid-connected and isolated local-voltage controlled modes is reported in [2].The indirect current control technique is proposed in [6] to mitigate voltage transients in mode transition. Seamless transition performance and robust control characteristics are reported in [2] via robust sliding-mode voltage controller and adaptive transient droop controller.

2. SYSTEM DESCRIPTION

In this system, a microgrid and a control part is shown in figure. A VSI is usually adopted for DG interfacing. A sample microgrid system with the proposed control direct voltage control structure is shown in Fig. 1. To achieve the objectives, the proposed control scheme employs an adaptive variable- structure voltage controller and a robustly designed power-sharing controller. Variable-structure control (VSC) perhaps is the best solution if the perturbations are random and nonlinear. VSC provides an effective nonlinear robust control approach. The VSC is an effective method to reject both internal and external disturbances in the system, which is a key requirement for seamless transfer in DG inverters. In this paper, a newly designed adaptive direct-voltage VSC scheme for the DG interface is proposed, overcomes the limitations of conventional VSC [1]. A power-sharing controller, transient droop controller against large power angle swings is proposed. The microgrid stability can be preserved at different operating conditions using two controllers. The power calculation is done using the following equations. The injected instantaneous active and reactive power components, *p* and *q*, using two axis theory are given by

$$p = 1.5\left(v_{od}i_{od} + v_{oq}i_{oq}\right) \quad (1)$$

$$q = 1.5\left(v_{od}i_{oq} - v_{oq}i_{od}\right) \quad (2)$$

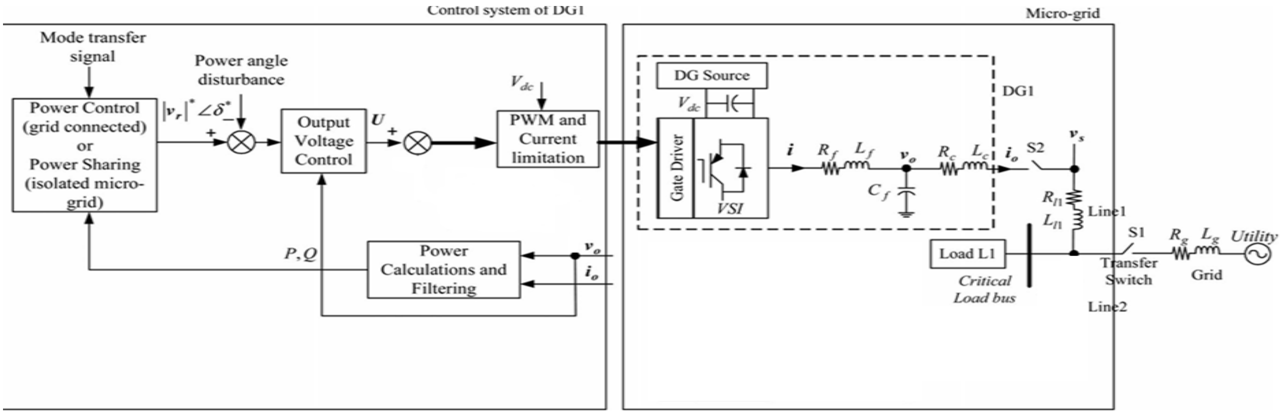


Figure 1: Sample Microgrid System with the Control Structure.

To achieve high power quality injection, the average active and reactive powers corresponding to the fundamental components are subjected to the control action, and they are obtained by means of a low-pass filter as

$$P=\frac{\omega_c}{s+\omega_c}p \quad (3)$$

$$Q=\frac{\omega_c}{s+\omega_c}q \quad (4)$$

where ω_c is the filter cutoff frequency.

3. METHODOLOGY

A sample microgrid with a direct voltage controller is shown in Fig. 2. The network switching disturbances, associated with the output current i_o, will result in voltage disturbances imposed on the output voltage magnitude of the inverter unit. But the power angle disturbances are generated due to mode transition and load/network switching and can be rejected by a relatively high bandwidth voltage control loop with high disturbance rejection performance.

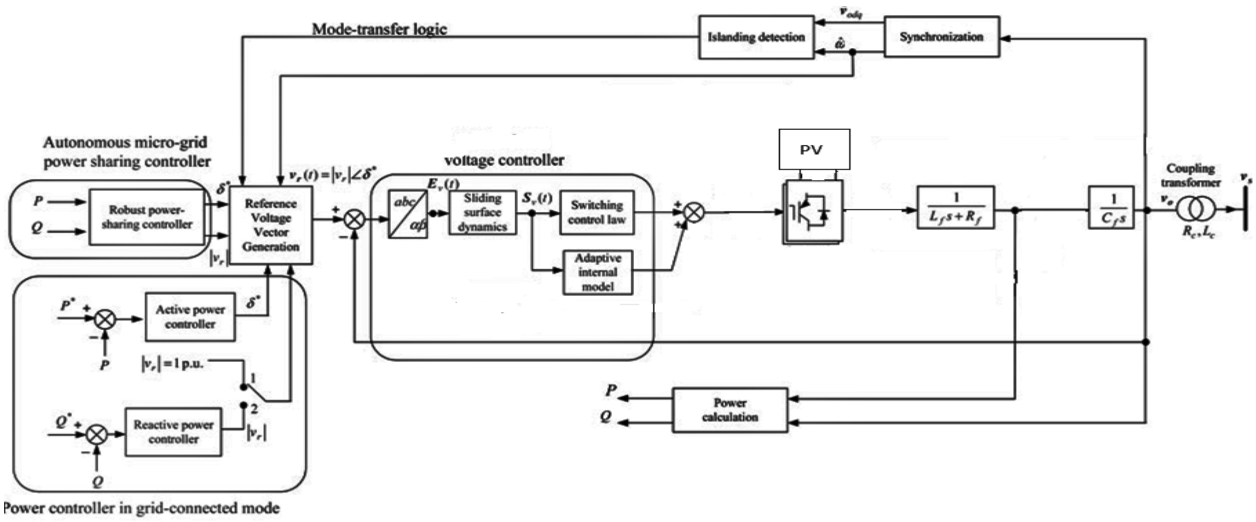


Figure 2: Proposed Control Structure with DG Source Photovoltaic System

3.1 Direct Voltage Controller

The main objective of the proposed voltage controller is to maximize the disturbance rejection performance for wideband of disturbances, and also to meet the voltage tracking requirements in both modes. To overcome the computational burden Clark's $\alpha\beta$ transformations are used in the voltage controller. The voltage dynamics in $\alpha\beta$ transformations can be written as (5). Where $d(t)$ is the dynamic disturbance imposed on the output voltage during mode transition and load variations and R_d is the LC filter damping coefficient. In practical conditions parametric uncertainties and other unstructured uncertainities are taken into account according to the various operating conditions. Then voltage dynamics can be written as

$$\begin{bmatrix} v_\alpha(t) \\ v_\beta(t) \end{bmatrix} = L_f C_f \begin{bmatrix} \frac{d^2 v_o^\alpha(t)}{dt^2} \\ \frac{d^2 v_o^\beta(t)}{dt^2} \end{bmatrix} + R_d C_f \begin{bmatrix} \frac{dv_o^\alpha(t)}{dt} \\ \frac{dv_o^\beta(t)}{dt} \end{bmatrix} + \begin{bmatrix} v_o^\alpha(t) \\ v_o^\beta(t) \end{bmatrix} + \begin{bmatrix} d_\alpha(t) \\ d_\alpha(t) \end{bmatrix} \quad (5)$$

$$\frac{d^2 v_o(t)}{dt^2} = a_0 \frac{dv_o}{dt} + b_o U(t) + g_o v_o(t) + W(t) \quad (6)$$

where "*o*" denotes the nominal value, "Δ" denotes deviation from nominal value, and ***W***(*t*) is the lump of uncertainties caused by parameter variation, and other unstructured uncertainties, Γ(*t*) is used to model ***W***(*t*).

$$W(t) = \Delta a \frac{dv_o(t)}{dt} + \Delta b U(t) + \Delta g v_o(t) + gD(t) + \Gamma(t) \quad (7)$$

$$a_o = \frac{1}{L_{fo} C_{fo}} \; ; \; b = -\frac{R_d}{L_{fo}} \; ; \; g = -\frac{1}{L_{fo} C_{fo}} \quad (8)$$

According to the VSC principle, the switching controller can be designed to reject the unpredictable perturbation effect due to parameter variation and external disturbances so that we will get the desired output. The control structure around the plant is varied due to some external influences to get the desired output. The desired output is achieved by driving the plant's state trajectory onto a chosen surface in the sliding mode. A particular differential-integral based sliding surface is selected so that it eliminates the reaching phase and remove steady-state errors associated with nonlinear sliding motion effects.

$$S_v(t) = k_1 E_v(t) + k_2 \int_0^t E_v(t) + \frac{dE_v(t)}{dt} \quad (9)$$

where *k*1 and *k*2 are the sliding surface control parameters, and

$$E_v(t) = v_o(t) - v_r(t) \quad (10)$$

is the voltage tracking error vector in the stationary reference frame, and ***Vr*** (*t*) is the reference voltage trajectory. The sliding surface dynamics can be obtained as

$$\frac{dS_v(t)}{dt} = k_1\frac{dE_v(t)}{dt} + k_2E_v(t) + \frac{d^2E_v(t)}{dt^2} \quad (11)$$

To assure global asymptotic stability of (11) the plant the VSC control effort is designed in such a way that it eliminates the disturbances. The control effort includes a tracking control effort ***U****v*−tr(*t*) and a disturbance rejection control effort ***U****v*−sw (*t*) as follows:

$$U_v(t) = U_{v-tr}(t) + U_{v-sw}(t) \quad (l2)$$

Where $U_{v-sw}(t) = -\frac{1}{b_o}K_{sw}$

$$K_{sw} = [K_{s1}sgn(S_{v\alpha}) \quad K_{s2}sgn(S_{v\beta})]T \quad (13)$$

where k_1 and k_2 are control parameters, $[K_{s1}\ K_{s2}\ ]^T > |\boldsymbol{W}|$ is a switching gain normally designed with large values. But large switching gains may lead to significant deviations from the sliding surface and result in control chattering. This reduces the robustness of the variable-structure controller. The operating conditions are not predictable so that the the uncertainty function dynamically varies with the operating conditions. The switching gains should be selected to cope with the worst and best operating conditions. An adaptive internal model is used to eliminate this control chattering. The internal model is chosen as the estimated function $\widehat{W}$, which adaptively varies with different operating conditions. The VSC law is designed with relaxed switching gains to reject imperfectly compensated disturbances and other random perturbations. The global asymptotic stability of sliding surface dynamics (k) is guaranteed, if the control law is designed as

$$U(t) = U_{v-tr}(t) + U^{\gamma}_{v-sw}(t) + U_{v-im}(t) \quad (14)$$

$$U^{\gamma}_{v-sw}(t) = -\frac{1}{b_o}K^{\gamma}_{sw}$$

$$K^{\gamma}_{sw} = [K^{\gamma}_{s1}sgn(S_{v\alpha}) \quad K^{\gamma}_{s2}sgn(S_{v\beta})\ ]^T$$

$$U_{v-im}(t) = -\frac{1}{b_o}\widehat{w} \quad (15)$$

$K^{\gamma}_{sw} = [K^{\gamma}_{s1}sgn(S_{v\alpha}) \quad K^{\gamma}_{s2}sgn(S_{v\beta})\ ]^T$ is the sliding gain vector with reduced switching gains, $\boldsymbol{U}_{v-\mathrm{im}}$ (*t*) is the internal model control effort, and γ is a positive constant.

3.2 Transient Droop Controller

To enhance the performance of the conventional droop controller, transient droop terms can be added. The controllability of the power-sharing controller is increased by using transient droop. The modified droop functions are given by

$$\omega_o = \omega^* - mP - m_d\frac{dP}{dt} \quad (16)$$

$$v^*_{od} = V^* - nQ - n_d\frac{dQ}{dt} \quad (17)$$

where m_d and n_d are the transient droop parameters. The design process of the conventional droop controller is usually conducted in the small-angle sense which may result in large power angle swings. The relative stability of the transient droop controller can be increased using an optimization technique, ie., particle swarm optimization technique[1].

4. MODELLING OF PHOTOVOLTAIC SYSTEM

The basic equation [1] from the theory of semiconductors that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$$I = I_{PVCell} - I_{0Cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (18)$$

where I_{PVCell} is directly proportional to the sun irradiation and it is current generated by the incident light
Where $I_d=I_{0,Cell}$ $[\exp\left(\frac{qV}{akT}\right) - 1]$
I_d -Shockley diode equation
I_{0Cell} - reverse saturation or leakage current of the diode.
q -electron charge [$1.60217646 * 10^{-19}$] in Columb (C)
T - Temperature of the *p-n* junction in Kelvin (K),
a - diode ideality constant,
k- Boltzmann constant [$1.3806503*10^{-23}$J/K]

4.1Modeling the photovoltaic array

In practical condition the equation (18) does not represent the I-V characteristic of a practical photovoltaic array. Practical arrays are composed of several connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic array requires the inclusion of additional parameters to the basic equation:

$$I = Ipv - Io\left[\exp\left(\frac{V+RsI}{Vta}\right) - 1\right] - \frac{V+RsI}{Rp} \quad (19)$$

Where I_{pv} and I_o are the photovoltaic and saturation currents of the array $V_{t=}$ N_sKT/q is the thermal voltage of the array with Ns cells connected in series. If the cells are connected in series it provides greater output voltage. And if in parallel connected it increases the current. If the array is composed of N_p parallel connections of cells the photovoltaic and saturation currents may be expressed as: $I_{PV}=I_{PV,Cell}$ N_p, $I_0=I_{0,Cell}N_{p.}$ In equation (19) R_S is the equivalent series resistance of the array and R_P is the equivalent parallel resistance.

The amount of incident light directly affects the generation of charge carriers and consequently the current generated by the device. It is difficult to determine the light-generated current (Ipv) of the elementary cells.Isc ≈ Ipv assumption is generally used in photovoltaic models because in practical devices the series resistance is low and the parallel resistance is high. The light generated current of the photovoltaic cell depends linearly on the solar irradiation. And this is influenced by the temperature according to the following equation:

$$Ipv = (Ipv,n + Ki\Delta T)\frac{G}{Gn} \quad (20)$$

$I_{pv,n}$ - the light-generated current at the nominal condition
$\Delta T= T - T_{n,}$ (T and Tn are the actual and nominal temperatures in Kelvin[K])
G [W/m2]- the irradiation on the device surface
Gn- nominal irradiation.
The diode saturation current I_o and its dependence on the temperature may be expressed by (21)

$$Io = Io,n(\frac{T}{Tn})^3\exp[\frac{qEg}{ak}(\frac{1}{Tn} - \frac{1}{T})] \quad (21)$$

Where E_g is the band gap energy of the semiconductor and $I_{o,n}$ is the nominal saturation current:

$$Io,n = \frac{Isc,n}{\exp\left(\frac{Voc,n}{aVt,n}\right)-1} \quad (22)$$

with $V_{t,n}$ being the thermal voltage of N_s series-connected cells at the nominal temperature T_n . The saturation current I_o mainly depends on the saturation current density and on the effective area of the cells. The nominal saturation current $I_{o,n}$ is indirectly obtained from the experimental data through (22), which is obtained by evaluating (19) at the nominal open-circuit condition. The value of the diode constant 'a' may be chosen arbiteraly as $1 \le a \le 1.5$ and the choice depends on other parameters of the I-V model. 'a' expresses the degree of ideality of the diode and it is totally empirical, any initial value of a can be chosen in order to adjust the model. To improve the model fitting 'a' can be adjusted. The photovoltaic model described in the previous section can be improved if equation (21) is replaced by:

$$Io = \frac{Isc,n+Ki\Delta T}{\exp\left(\frac{Voc,n+Kv\Delta T}{aVt}\right)-1} \quad (23)$$

By including voltage coefficients K_V and K_i, we get the above equation. The photovoltaic array can be simulated with an equivalent circuit model based on the photovoltaic model .The value of the model current Im is calculated and Ipv is obtained from (20). Using MATLAB/SIMULINK the photovoltaic system is implemented.

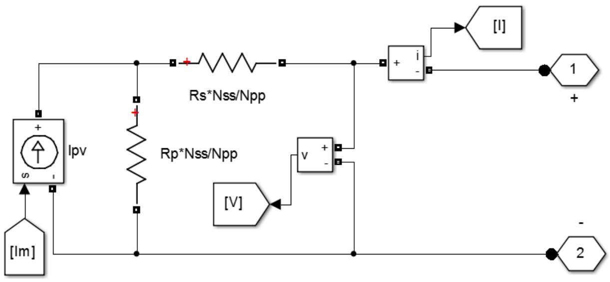


Figure.3: Photovoltaic Circuit model

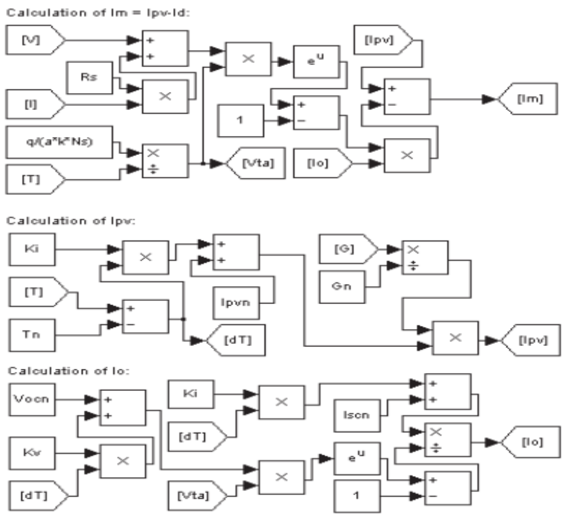


Figure 4: Calculation of Im, Ipv and Io

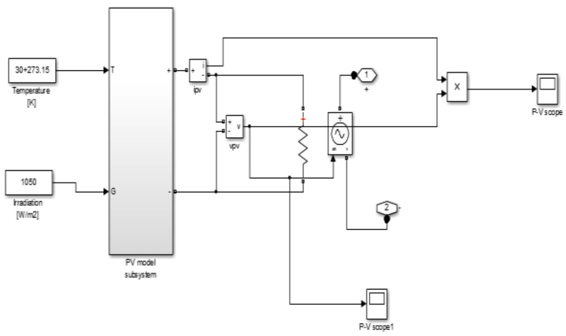


Figure.5: Photovoltaic Circuit model subsystem

5. TEST RESULTS

To evaluate the performance of the proposed control scheme, the microgrid test system, the overall system is implemented in MATLAB/Simulink environment. The islanding detection block detects the mode, ie.in either in grid connected or in islanded mode. First it will be in grid connected mode and from 0.1 to 0.2 breaker opens and detect the islanded mode. The frequency and voltage tolerance is respectively given as +/- 3% and +/- 5%.

Voltage (V)

Mode

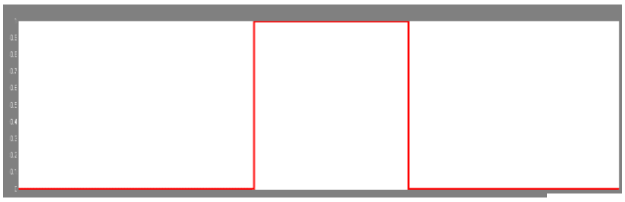
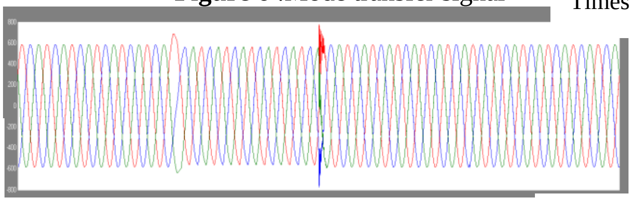


Figure 6 :Mode transfer signal

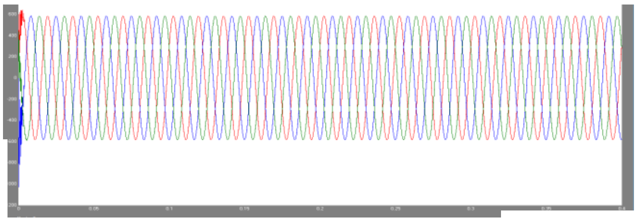
Times (s)



Voltage (V)

Times (s)

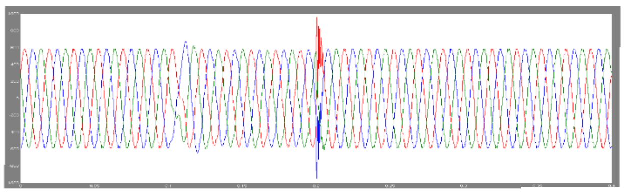
Figure 7: a) Load voltage in grid connected and isolated mode with controller in balanced load



Voltage (V)

Times (s)

b) Load voltage in isolated mode with controller in unbalanced load



Times (s)

c) Load voltage in grid connected and isolated mode with controller in nonlinear load

6. CONCLUSION AND FUTURE ENHANCEMENT

The robust and flexible microgrid operation with seamless transfer in the transition mode has been obtained using two controllers. The performance of voltage controller and power sharing controller contribute to the microgrid stability and reliability in the smart grid environment. A control structure for seamless microgrid formation and robust operation in grid connected and isolated modes with DG source as PV are presented in this paper. The PV is interfaced properly so that all the disturbance are eliminated. The proposed voltage and power-sharing controllers provide high disturbance rejection performance against voltage disturbances and power angle swings, respectively. The paper can be extended with an adaptive variable structure controller using one of the optimization technique .Due to wide search space capacity Particle swarm optimization (PSO) can be used in variable structure controller hence the name adaptive. The controller is designed to eliminate the reaching phase in conventional VSC schemes. This feature increases the robustness against fast voltage disturbances

7. ACKNOWLEDGEMENT

Authors are thankful to Mr. Anil Antony , Asst.Professor ,EEE Department, Thejus Engineering College, Thrissur, for his valuable support and guidance.

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